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ON-BOARD PROCESSING ARCHITECTURES FOR SATELLITE B-ISDN SERVICES[1]

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SUMMARY

This paper addresses on-board baseband processing architectures for future satellite broadband integrated services digital networks (B-ISDNs). To assess the feasibility of implementing satellite B-ISDN services, critical design issues, such as B-ISDN traffic characteristics, transmission link design, and a trade-off between on-board circuit and fast packet switching, are analyzed. Examples of the two types of switching mechanisms and potential on-board network control functions are presented. A sample network architecture is also included to illustrate a potential on-board processing system.

1. INTRODUCTION

The B-ISDN will likely play a major role in the future telecommunications networking for providing high speed integrated services to network users such as broadband video-telephony, broadband videoconference, high volume file transfer, high speed telefax, high definition TV (HDTV), and broadband videotext. It is envisaged that this technology will have an impact on satellite communications. This paper addresses some of the key design issues and alternate on-board switching architectures for a satellite-based B-ISDN.

The paper presents examples of B-ISDN traffic characteristics and identification of potential satellite applications of B-ISDN services. One of the primary concerns in designing a satellite B-ISDN system is the design of a transmission link that can support very high data rates ranging from 155 Mbit/s to over 1 Gbit/s with an availability that is comparable to terrestrial-based services. A summary of link analysis for Ku- and Ka-bands is included in the paper.

One of the most critical design issues for on-board processing satellites is the selection of an on-board baseband switching architecture. Circuit switching and fast packet switching are probably the two most common architectures. A trade-off analysis is performed for these architectures on the capability of handling circuit- and packet-switched traffic and the impact of traffic reconfiguration. Several switch structures for the two types of switching are also illustrated.

Potential satellite network architectures for B-ISDN include baseband-switched TDMA (SS-TDMA), TDMA up-link/TDM down-link, TDM up-link/TDM down-link, and hopping beam TDMA. SS-TDMA requires simpler on-board hardware and provides flexible connectivity among the same type of earth stations. TDMA up-link/TDM down-link allows the use of shared up-link capacity by multiple earth stations, while optimizing down-link transmission on a single carrier. It will require an on-board baseband processor for rate conversion and interconnection of user traffic. TDM up-link/TDM down-link is particularly suited for trunking applications and circuit-switched B-ISDN traffic. As in the previous case, an on-board processor provides rate conversion and connectivity. Thin-route traffic can be efficiently carried by hopping beam TDMA to dynamically

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allocate the necessary capacity to different dwell areas. The paper presents a sample network architecture with TDMA up-link and TDM downlink and on-board fast packet switching.

2. SATELLITE APPLICATIONS

The B-ISDN supports a wide variety of communications services. Although the B-ISDN is being developed primarily for terrestrial networking using fiber optic cables, satellites are well positioned in complementing terrestrial-based B-ISDN services. The satellite-based system has inherent capabilities of providing multipoint/broadcast transmission, connectivity between any two points within a beam coverage, quick reallocation of space segment capacity, and distance-insensitive cost. Use of multiple spot beams and on-board rate conversion/switching will provide a larger capacity, additional flexibility, and lower user terminal cost. The satellite B-ISDN system can be used for direct (mesh) interconnection among users (UNI-UNI), interconnection between a user and a switching node (UNI-NNI), and interconnection between switching nodes (NNI-NNI). Figure 1 illustrates these options.

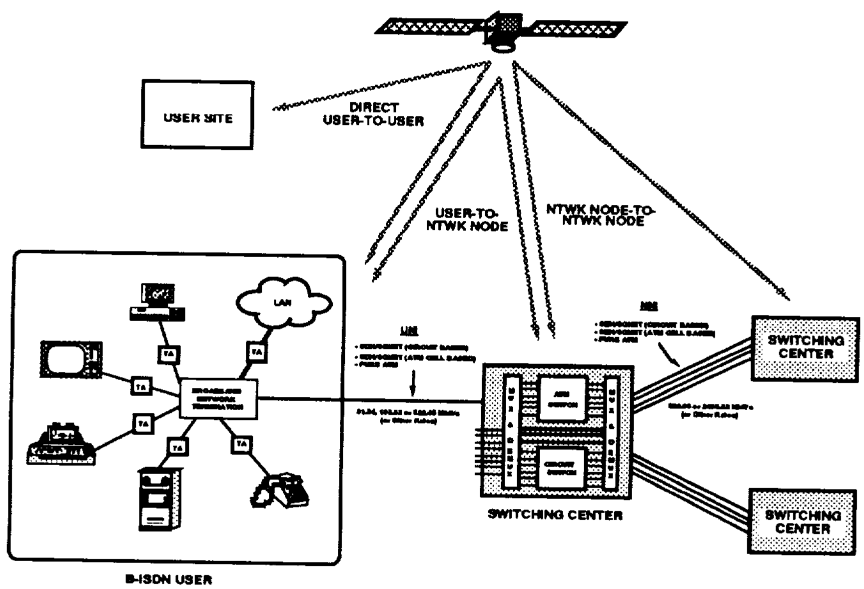

Figure 1. A satellite B-ISDN can provide direct interconnection between users, switching centers, and a user and a switching center.

A variety of B-ISDN services can be supported by a satellite network. Table 1 depicts examples of satellite B-ISDN services and their typical traffic characteristics. The B-ISDN interface rates are 155.52 Mbit/s (51.84 Mbit/s for SONET STS-1) or higher, but their information rates can be as small as 64 kbit/s. Traffic can be extremely bursty such as in LAN/MAN interconnection, or can be a steady flow of high speed data as in video program distribution. A satellite network must be flexible to accommodate a wide range of transmission rates and different degrees of burstiness. In addition, Asynchronous Transfer Mode (ATM) is a packet-based transmission mechanism that supports connection-oriented as well as connectionless services at various bit rates. Thus, a satellite system design must take into account these new environments that are significantly different from the traditional circuit-oriented system.

Table 1. Traffic Characteristics of Satellite B-ISDN

SAMPLE APPLICATION	BIT RATE RANGE (Mbit/s)	BURSTINESS	SOURCE TRAFFIC TYPE
Video Distribution	45 - 140	Low	Circuit
Live Newscast/Broadcast	20 - 45	Low	Circuit
Science Data Distribution	30 - 300	Medium	Circuit/Packet
Supercomputer Networking	30 - 1000	High	Packet (Circuit)
Private Networking	0.1 - 100	High	Packet (Circuit)
Trunking	52 - 2500	Low	Circuit
Emergency Communications	2 - 45	Low to Medium	Circuit (Packet)
Thin-Route Networking	0.1 - 10	Medium to High	Packet (Circuit)

3. TRANSMISSION LINK DESIGN

As seen in the previous section, the satellite B-ISDN network must support a wide range of bit rates from as low as 64 kbit/s to over 1 Gbit/s. A link analysis was performed for typical Ku- and Ka-band satellites to determine typical bit rates that can be supported by various earth station sizes (HPA and antenna). A Ku-band spot beam satellite assumes INTELSAT-VII or typical domestic satellite parameters with a G/T of 5 dB/K and an EIRP of 50 dBw, and a Ka-band satellite has a G/T of 20 dB/K and an EIRP of 60 dBw (ACTS parameters). It is also assumed that these satellites perform on-board regeneration as well as FEC decoding and recoding. The results of link analysis are shown in Table 2.

Table 2. Link Analysis Results (QPSK Modulation, BER=10-8)

FREQ. BAND.	ANTENNA DIAMETER (m)	HPA SIZE (watts)	BIT RATE (Mbit/s)	FEC CODING RATE	UPLINK MARGIN (dB)	DOWNLINK MARGIN (dB)
Ku	12.0	100	620	0.75	10.8	12.5
	9.0	100	620	0.75	8.3	10.0
	7.5	100	310	0.5	10.8	12.5
	5.0	50	155	0.5	7.3	12.0
	2.4	50	50	0.5	5.8	10.5
	2.4	20	10	0.5	8.9	10.5
	1.2	20	10	0.5	2.8	4.5
Ka	12.0	100	1240	0.75	22.8	15.8
	9.0	100	1240	0.75	20.3	13.3
	5.0	50	620	0.5	16.3	12.3
	5.0	50	310	0.875	17.3	13.3
	2.4	50	155	0.5	15.9	11.9
	2.4	20	50	0.5	16.9	16.9
	1.2	20	10	0.5	17.8	10.8

The results indicate that an information rate of over 1 Gbit/s can be supported by a large Ka-band earth station, and small VSAT class terminals can be used for bit rates of up to 155 Mbit/s. A relaxed BER requirement, e.g. 10^{-6}, will result in a greater margin, a smaller antenna/HPA size, or a higher bit rate. If an additional margin or a lower threshold BER, e.g. 10^{-11}, is needed, a high-rate outer code, such as a Read-Solomon code, may be used with a slight increase in the required bandwidth.

4. CIRCUIT OR FAST PACKET SWITCHING?

On-board baseband switching provides interconnection of user earth stations operating at different bit rates and access schemes. There are two types of switching architectures that can be used for baseband switch implementation: (a) circuit switching and (b) fast packet switching. Circuit switching uniquely maps uplink time slots to downlink time slots and guarantees their connections until a controller deallocates the assigned slots. In fast packet switching, data are packetized into a fixed format with a routing header, and packets from earth stations are routed to the destination beams (or carriers) according to header information[2]. No fixed mapping exists between uplink slots and downlink slots. However, there is a potential on-board buffer overflow problem. A comparison of the two switching architectures is shown in Table 3.

Table 3. Comparison of Circuit and Fast Packet Switching

SWITCHING ARCHITECTURE	CIRCUIT-SWITCHED TRAFFIC	PACKET-SWITCHED TRAFFIC	TRAFFIC RECONFIGURATION
CIRCUIT SWITCHING	• Efficient Bandwidth Utilization	• Very Inefficient Bandwidth Utilization • Inflexible Connectivity	• Reprogramming of On-Board Switch Control Memories • Reconfiguration of Earth Station Time/Frequency Plans for Each Circuit Setup • Difficult to Implement Autonomous Private Networks
FAST PACKET SWITCHING	• Can Accommodate Circuit-Switched Traffic • Somewhat Higher Overhead Due to Packet Headers	• On-Board Congestion May Occur	• Self-Routing • Does not Require Control Memory for Routing • Reconfiguration of Earth Station Time/Frequency Plans for Major Traffic Changes • Easy to Implement Autonomous Private Networks

From this table, the following conclusions can be made:

a. Select circuit switching for circuit-switched traffic without frequent traffic reconfiguration.

b. Select fast packet switching for packet-based traffic or circuit-switched traffic with frequent channel reconfiguration. Special consideration must be given to the on-board congestion problem.

The congestion problem for fast packet switching can be completely eliminated for circuit-switched traffic by allocating a desired capacity (on a call-by-call basis) for both uplink and downlink carriers. For packet-switched traffic, some form of flow/congestion control is needed to minimize on-board buffer overflow. The techniques include the following: (a) a dynamic allocation of fixed capacity from a transmit earth station to each downlink carrier, (b) call admission control at the earth station, (c) on-board capacity allocation based on current queue status, (d) feedback control, and (e) a combination of these. The goal of flow/congestion control is to achieve a certain packet

[2]On-Board Processing Satellite Network Architecture and Control Study, Final Report, NASA Contract NAS3-24886, Prepared by COMSAT Laboratories, June 1987. Also, see a paper by S. J. Campanella and B. A. Pontano, "Future Switching Satellite," AIAA 12th International Communication Satellite Systems Conference, Virginia, pp. 264-273, March 13-17, 1988.

loss ratio within a satellite system such that no significant degradation results in the end-to-end performance. Some of these techniques have been successfully tested at COMSAT Laboratories.

The on-board switch selection described above is a general guideline based on a qualitative trade-off and should be carefully evaluated for specific applications, considering a total system capacity, traffic types, user traffic volume, and network connectivity.

5. ON-BOARD BASEBAND SWITCHING ARCHITECTURES

The simplest form of a baseband circuit switch consists of a space switch, such as the one used in the ITALSAT system, to provide SS-TDMA operation. The space switch allows dynamic interconnection among uplink and downlink spot beams according to the switch state configurations stored in the on-board control memory. It provides high speed interconnection most efficiently with a minimum amount of hardware and is also capable of providing multicast connectivity. A typical B-ISDN application of SS-TDMA includes HDTV program distribution, trunking, and cable restoration.

More flexible circuit switching to provide rate conversion and channel demultiplexing/multiplexing is achieved by the use of on-board data memory. Examples of this type of switch are a common memory (T-stage) switch, a distributed output memory with a parallel data bus (S-T), and a distributed input/output memory with a space switch (T-S-T). Figure 2 illustrates these switch structures. Also shown in the figure is a switch structure using a high speed fiber optic ring. The common memory structure possibly requires the least amount of hardware, but its capacity is limited by the memory access speed. The capacity of a distributed output memory structure depends on the speed of the parallel bus, and a careful design is required to avoid signal interference among the bus lines. The T-S-T structure is modular in design and can accommodate a larger capacity, but it may require a larger buffer size. The fiber optic bus is also modular in design, embodies a fault-tolerant structure, and can achieve a high throughput. Selection of a particular switch structure must consider the throughput requirement, a redundancy structure, and mass/power requirements.

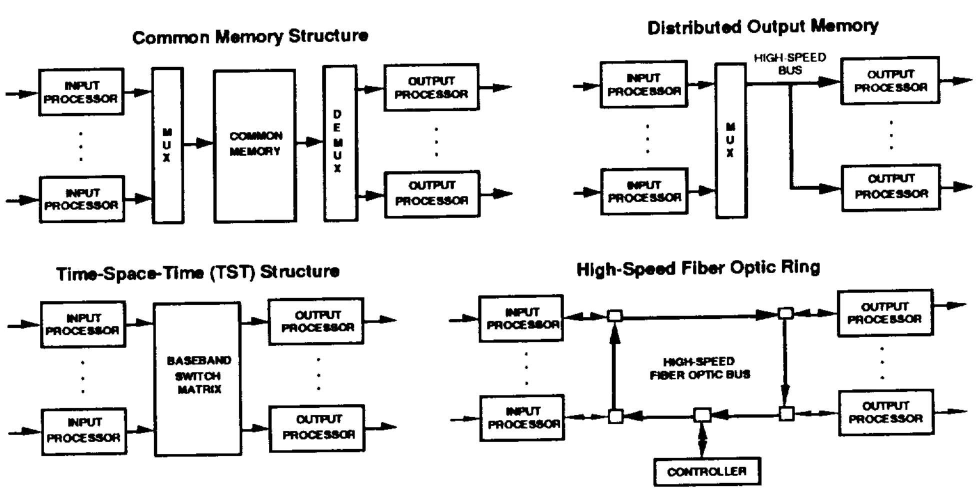

Figure 2. Examples of Circuit Switch

Fast packet switching allows dynamic routing of small packets to desired destination beams solely based on their routing headers. The routing function is performed with a hardware-oriented self-routing architecture. In fast packet switching, the bandwidth assigned to each connection can be instantaneously varied, which circuit switching cannot achieve. The interconnection network of the packet switch decides the performance of the switch such as delay and throughput. The circuit switch structures described above, except T-S-T, can also be used for fast packet switching, but the switch throughput is limited by the speed of the shared memory or the shared medium.

The space-division network can set up multiple connections from different input ports to different output ports. Since packet transfer is done in parallel, the switching network speed is reduced compared with the shared-memory and shared-medium schemes. The other advantage is that routing control can be distributed over the switching fabric. Examples of space division switching networks are shown in Figure 3.

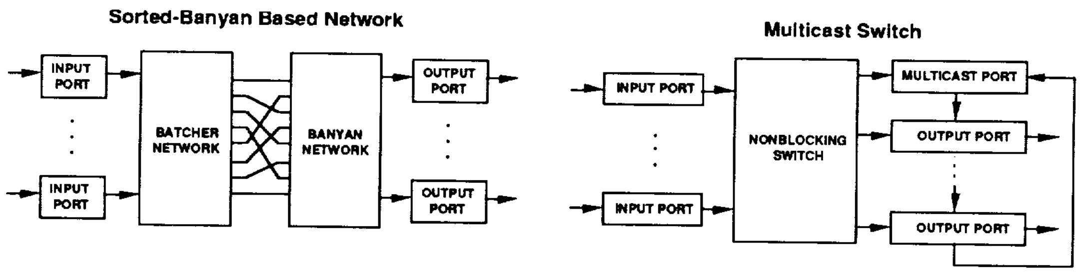

Figure 3. Examples of Fast Packet Switch Using a Space Division Switching Network

The space-division switching network can be implemented either in electronics, optoelectronics, or optics. The maximum data rate of a switch is a function of the device technology and the delays of the links. The VLSI technologies such as GaAs can support a data rate of up to several thousand Mbit/s. Other fast VLSI technologies are ECL and high speed CMOS.

Fast packet switching is particularly suited for providing dynamic interconnection of users with bursty traffic. Its application is not limited to only ATM users but includes lower speed traffic users with N-ISDN circuit-switched or packet-switched (X.25/frame relay) traffic.

In the conventional transparent satellites, network control functions, such as allocation of space and ground segments, demand assignment processing, and earth station monitor and control are performed by a ground-based network control station (NCS) through orderwire communication channels. The NCS is often equipped with sophisticated computer systems to perform real-time and batch processing to support dynamic network operation. Implementation of network control functions on board the satellite not only simplifies ground-based network control, but also provides a more efficient, reliable, and simpler interface (i.e., direct error-free connection between the on-board processor and the controller) and a lower ground segment cost. Some of the key on-board network controller (OBNC) functions are shown in Figure 4.

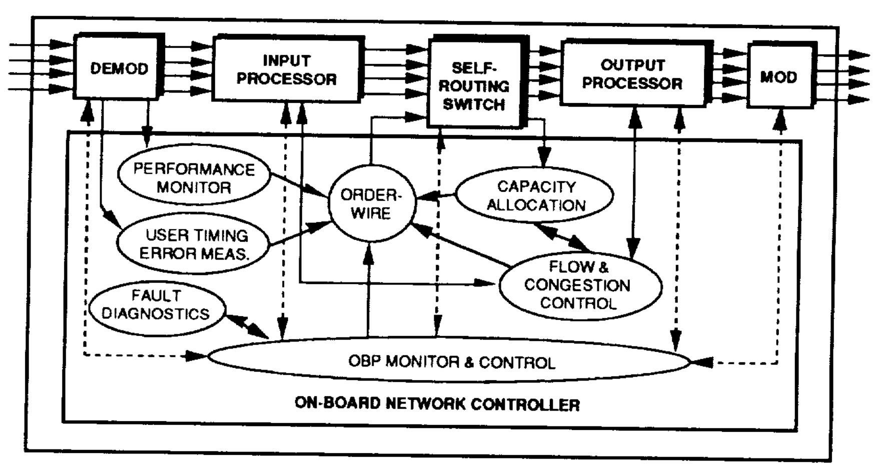

Figure 4. On-Board Network Controller Functions

To minimize the complexity of implementing these functions, expert systems and/or neural network technology may be fully utilized.

7. SAMPLE NETWORK ARCHITECTURE

A sample network architecture for an advanced on-board processing system is illustrated in Figure 5. The system consists of 15 Ka-band steerable beams and 13 Ku-band fixed spot beams, both covering the CONUS. The Ka-band beams can be parked on any of the 87 spot beam areas according to the beam traffic requirements. Each beam supports 155 Mbit/s TDMA transmission. The Ku-band system operates on an uplink TDMA bit rate of 5 Mbit/s and 10 carriers per beam and a single carrier TDM downlink at 50 Mbit/s. The Ku-band system is primarily used by low traffic users, for example, with N-ISDN interfaces. The two types of systems are interconnected by a 20 x 20 155-Mbit/s baseband switch matrix (BSM) and an 18 x 18 fast packet switch. The system capacities are respectively 2.3 Gbit/s and 650 Mbit/s for Ka- and Ku-bands, and a simple non-blocking switch structure shown in Figure 2 may be used for fast packet switch implementation.

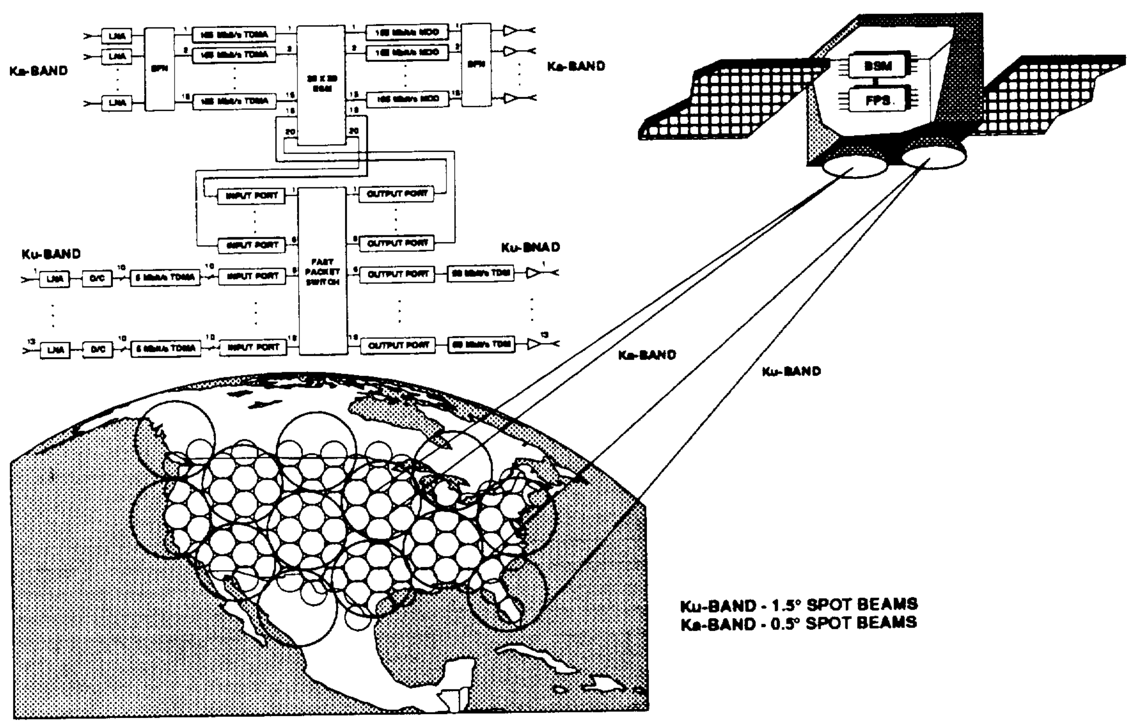

Figure 5. Sample Network Architecture

8. CONCLUSION

Satellite systems can provide B-ISDN services at bit rates of up to 1.24 Gbit/s with an antenna size of 9 m (Ka-band). However, user bit rates can be significantly smaller than this upper bound in most applications. A typical information rate may vary in the range of 100's kbit/s to 10's Mbit/s with occasional requirements at 52 Mbit/s and at up to 155 Mbit/s. In this scenario, cost-effective satellite integrated digital services can be provided to users with an antenna size of 1.8 - 2.4 m, and the use of fast packet switching on board the satellite will simplify overall network control and provide additional flexibility.